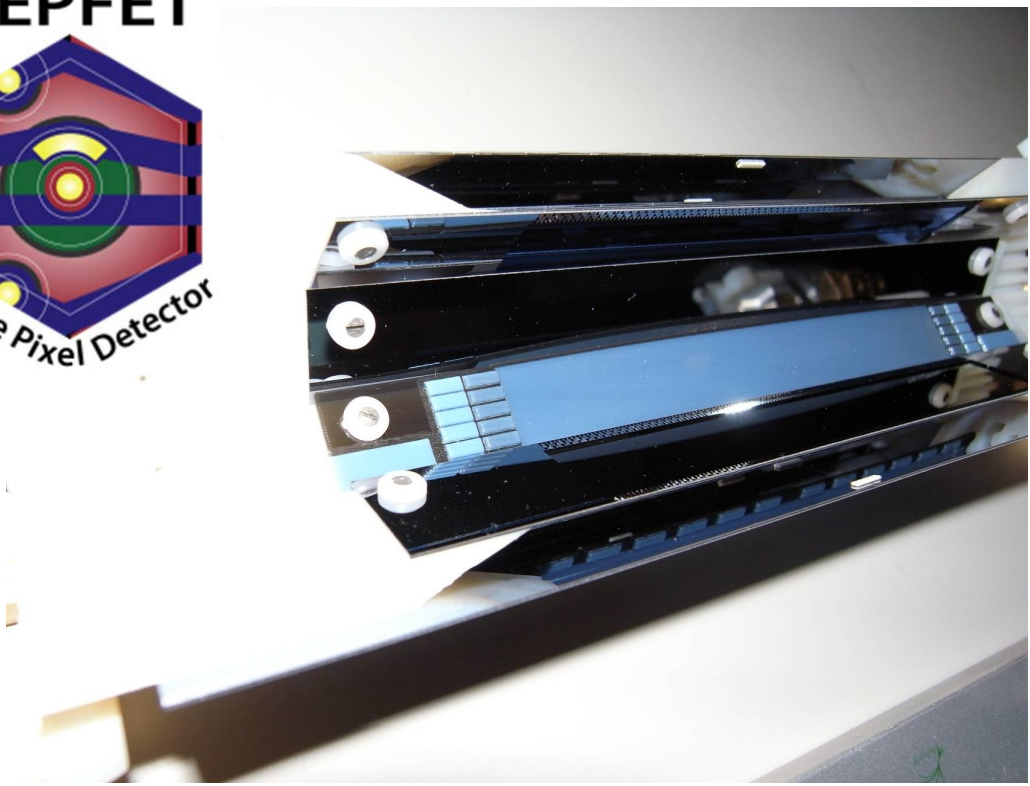
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Belle II

B-Physics with Belle and Preparations for Belle II at SuperKEKB

L. Li Gioi for the MPP Belle(II) group

DEPFET Active Pixel Detector



- Physics motivation
- Belle data analysis with the full dataset at MPP
- Belle II and the PXD Project
  - Sensor production and test
  - Mechanics and CO2 Cooling
- Belle II Physics preparation
- Belle II Software development
- Belle II Schedule

The Belle(II) group at MPP

- **Director:** Allen Caldwell.
- **Project Leader:** Hans-Günther Moser.
- **Staff:** Christian Kiesling, Vladimir Chekelian.
- **Postdocs:** Paola Avella, Luigi Li Gioi, Bogdan Lobodzinski, Martin Ritter, Thorsten Röder, Manfred Valentan.
- **PhD Students:** Fernando Abudinen, Veronika Chobanova, Felix Müller, Elena Nedelkovska, Andreas Ritter, Pit Vanhoefer.
- **Master Students:** Martin Hensel, Stephan Koopmans, Philipp Leitl, Christian Roca Catala.
- **Technical Support:** Karlheinz Ackermann, Benjamin Müller, Sven Vogt.
- **Strong support from HLL**
- **Guests from TUM :** Sara Neuhauser (PhD Student), Sebastian Skambraks (PhD Student).

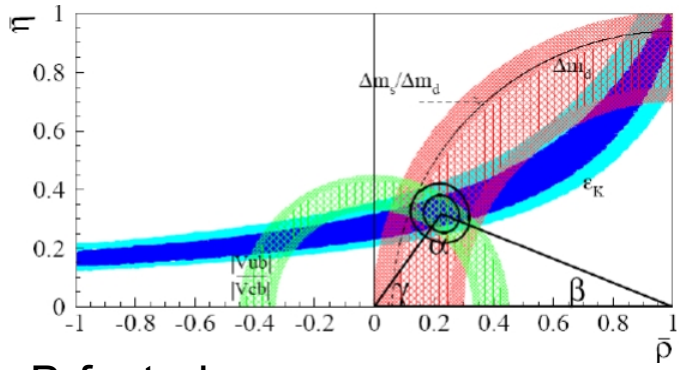
Left during 2014

Official Positions of MPP members within the Belle/Belle II Collaborations:

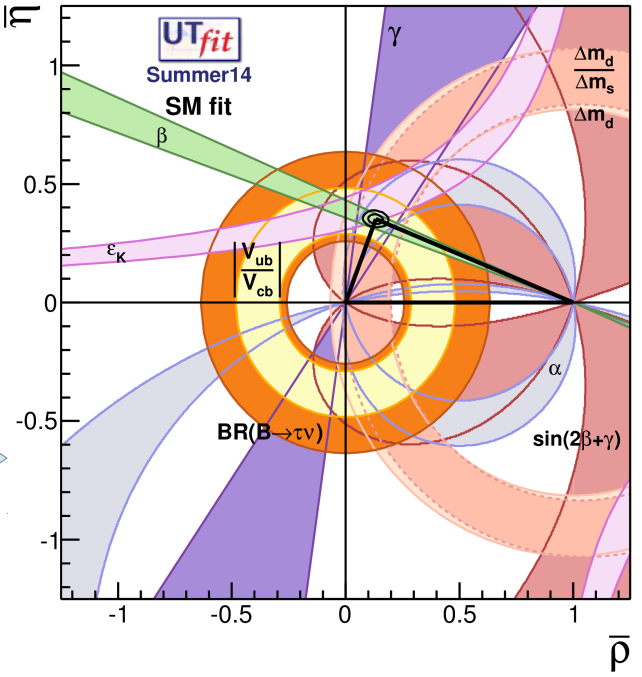
- **Christian Kiesling:** Spokesman of the DEPFET Collaboration, Co-Groupleader of the Subdetector PXD within Belle II, Member of the Belle Executive Board.
- **Hans-Günther Moser:** Technical Coordinator (DEPFET Collaboration), Co-Groupleader of the Subdetector PXD within Belle II, Member of the Belle/Belle II Collaboration Boards.
- **Luigi Li Gioi:** Working Group experimental convenor of the Belle II Theory Interface Platform, Belle II contact person for the RZG Tier 2.

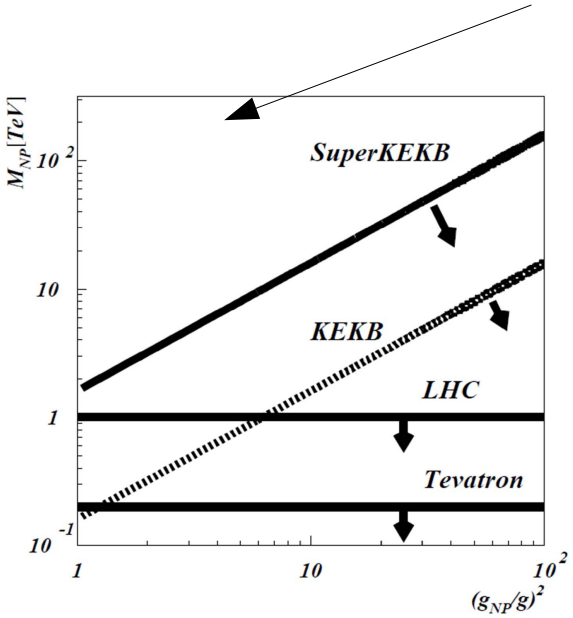
Physics motivation

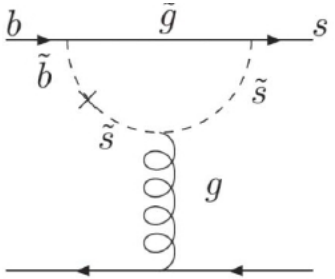
After the B-factories



Before the B-factories

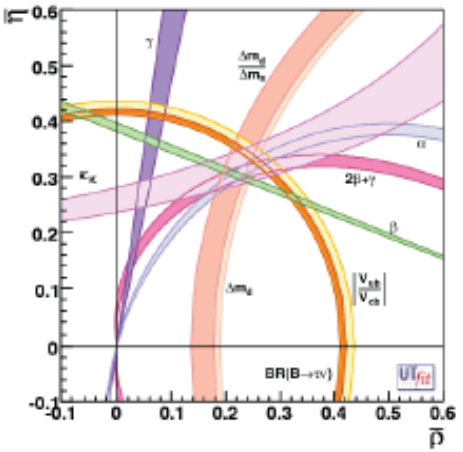






Indirect discovery of New Physics in quantum loops via high precision measurements

CKM matrix will be tested at 1% level

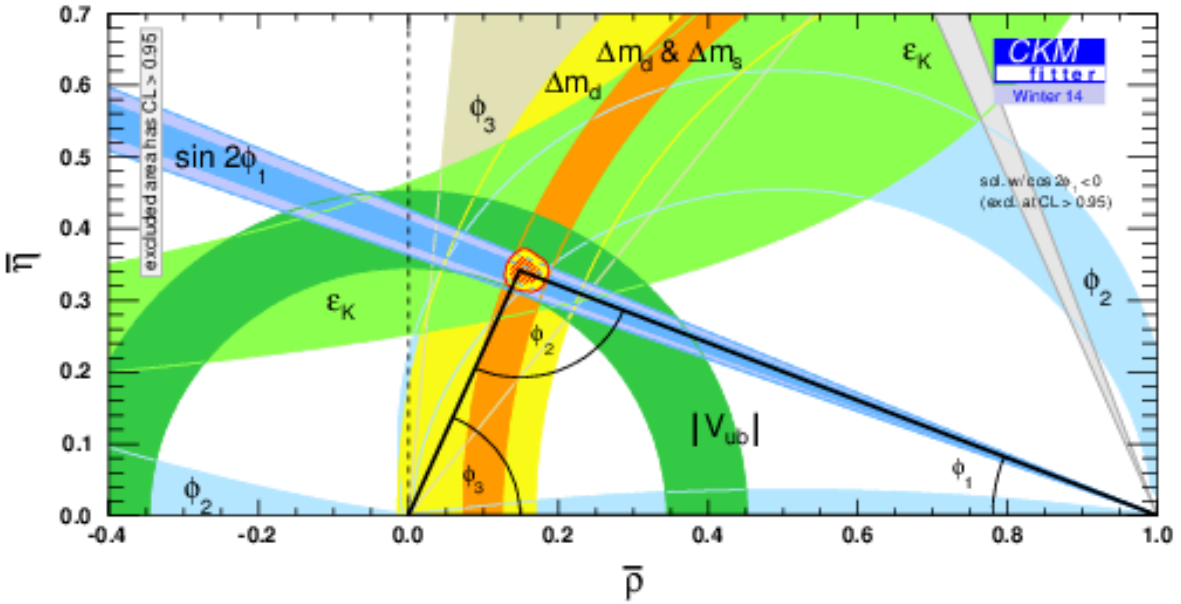


After Belle II ?

Lucky scenario

Belle data analysis

- Final analysis using complete Belle data set (711 fb^{-1}, 772x10^6 $B\bar{B}$-events)
- 2014: 2 paper with MPP members as primary authors
  - 17 papers published by Belle



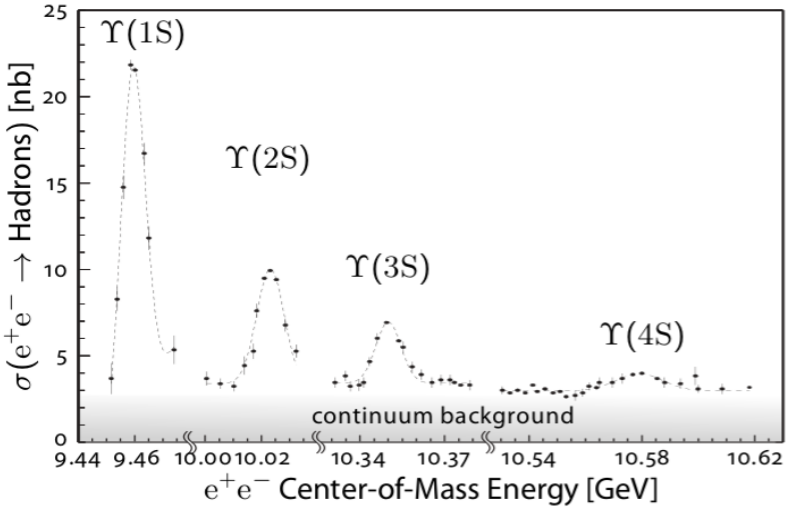
Activities at MPP focused on the measurement of the angles ϕ_1 and ϕ_2:

ϕ_1
- $B^0 \rightarrow \omega$ Ks
- $B^0 \rightarrow D^{*+} D^{*-}$ Ks
- $B^0 \rightarrow \psi(2S)\ \pi^0$

ϕ_2
- $B^0 \rightarrow \rho^0 \rho^0$
- $B^0 \rightarrow \rho^+ \rho^-$

Published

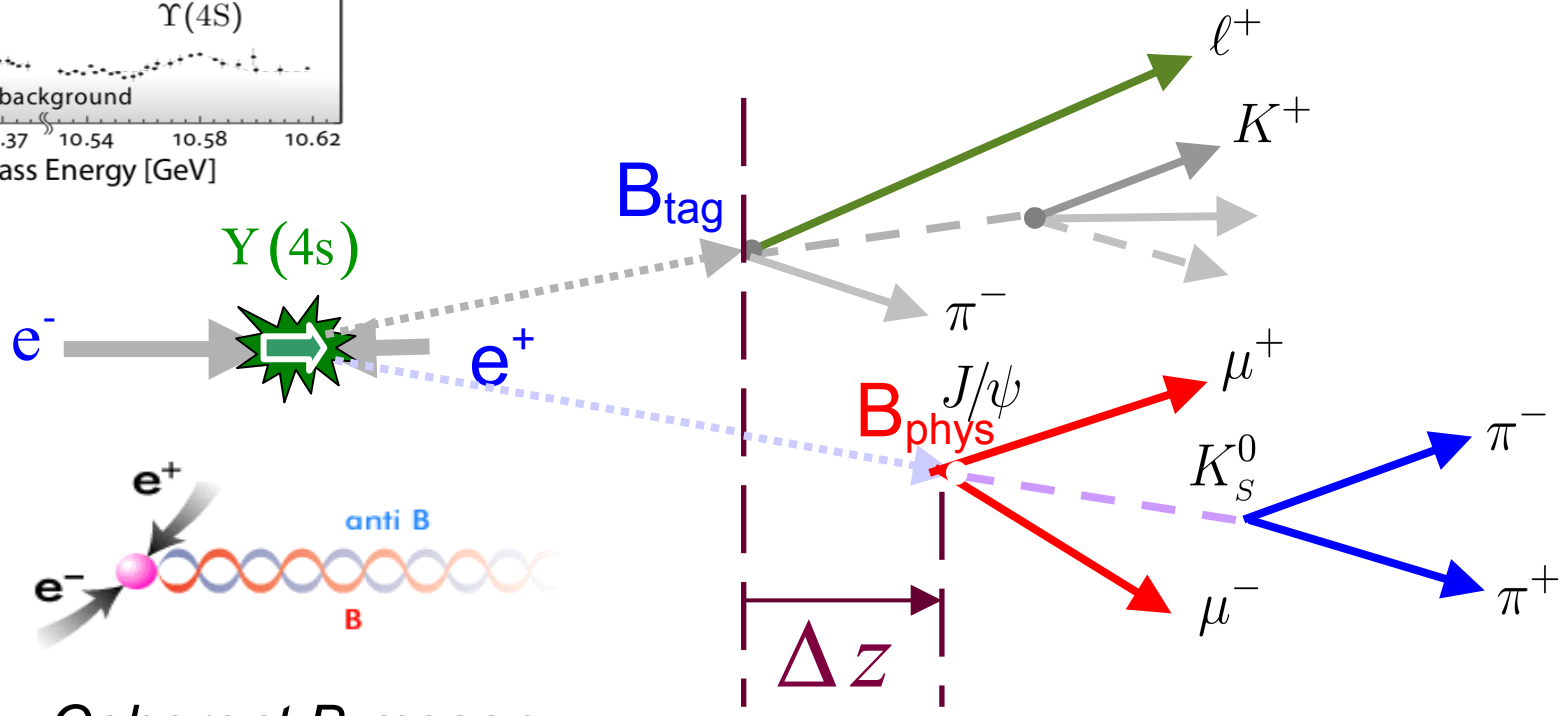
Time dependent measurements



- Y(4S) is the first resonance just above the $B\bar{B}$ production threshold
- Only $B\bar{B}$ pairs are produced, and are at rest in the Y(4S) frame

$$\Delta t = \frac{\Delta z}{\beta \gamma c}$$

Resolution on Δt will be dominated by the resolution of the tagging side vertex



Coherent B meson pair production

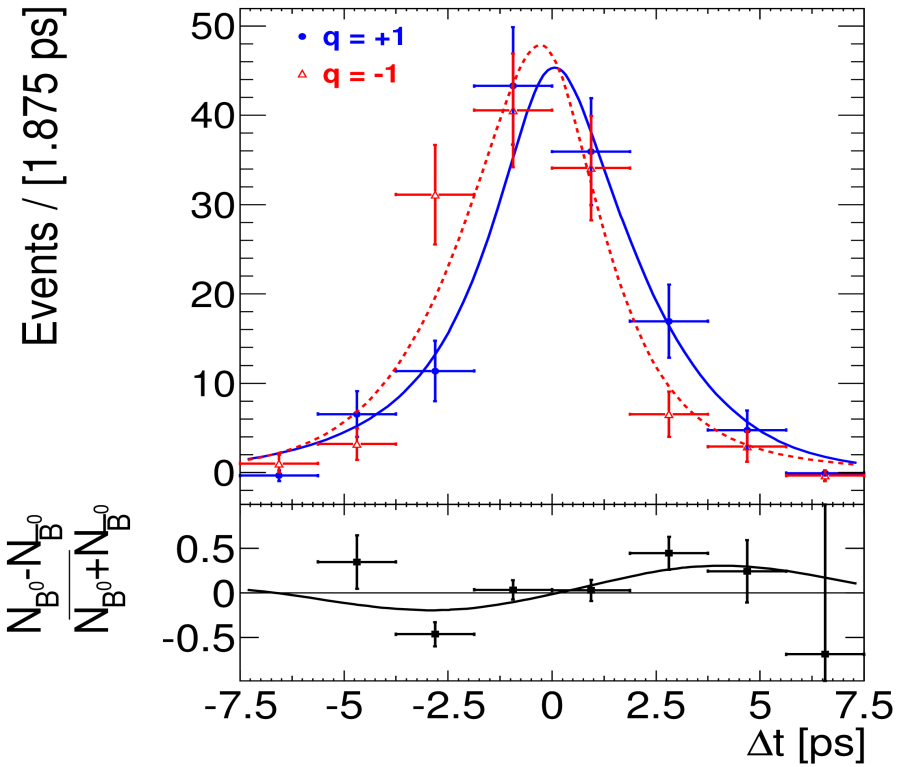
Belle ~ 200 μm
Belle II ~ 130 μm

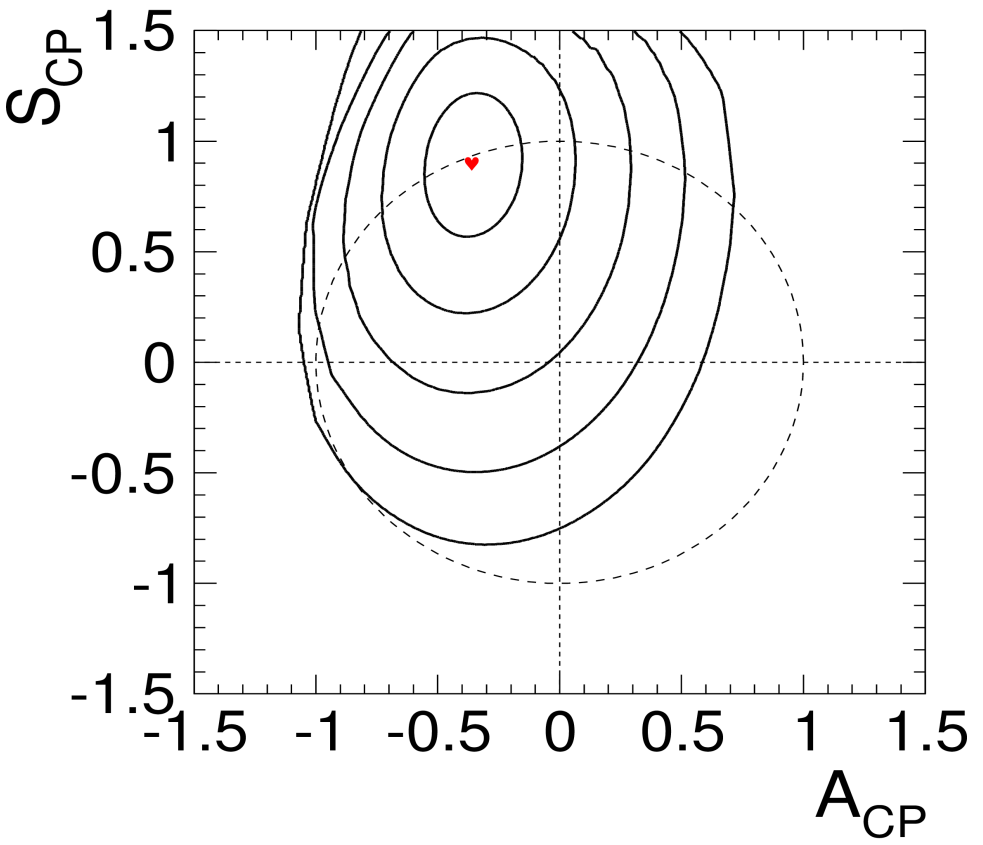
Δt probability parametrization $\mathcal{P}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\left[1 + q\left(\mathcal{A}_{CP}\cos\Delta m_d \Delta t + \mathcal{S}_{CP}\sin\Delta m_d \Delta t\right)\right]$

V. Chobanova

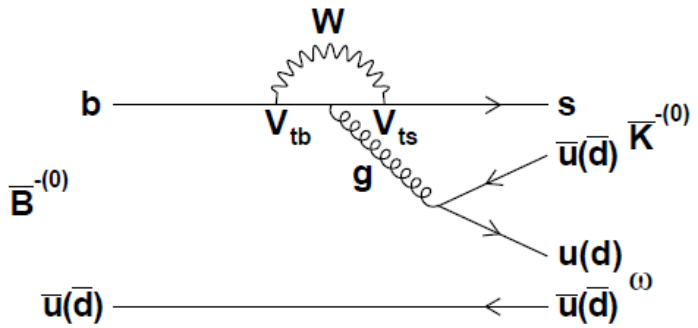
Sin(2ϕ_1): $B^0 \to \omega K_S$

PRD 90, 012002 (2014)





$$a_{CP} = A(\omega K^0_S)\cos(\Delta m_d \Delta t) + S(\omega K^0_S)\sin(\Delta m_d \Delta t)$$

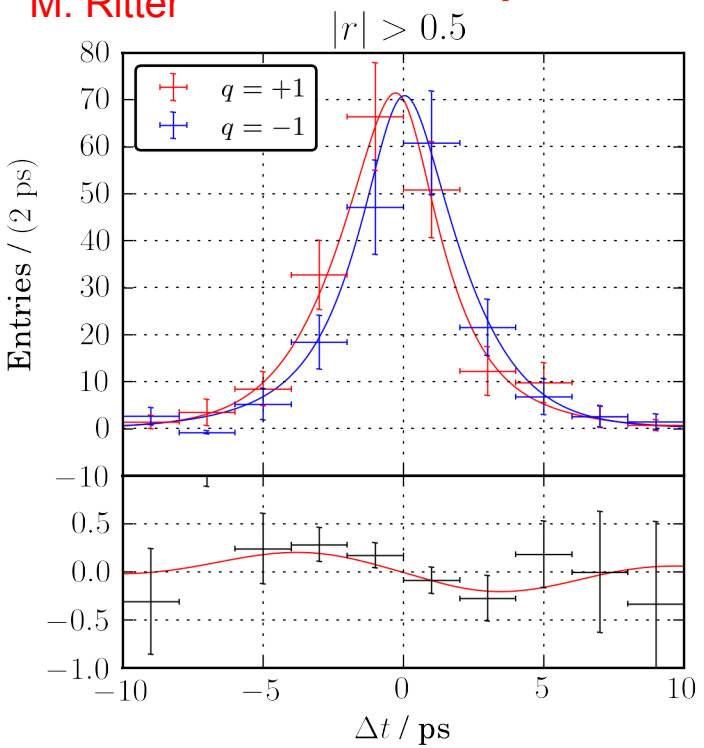


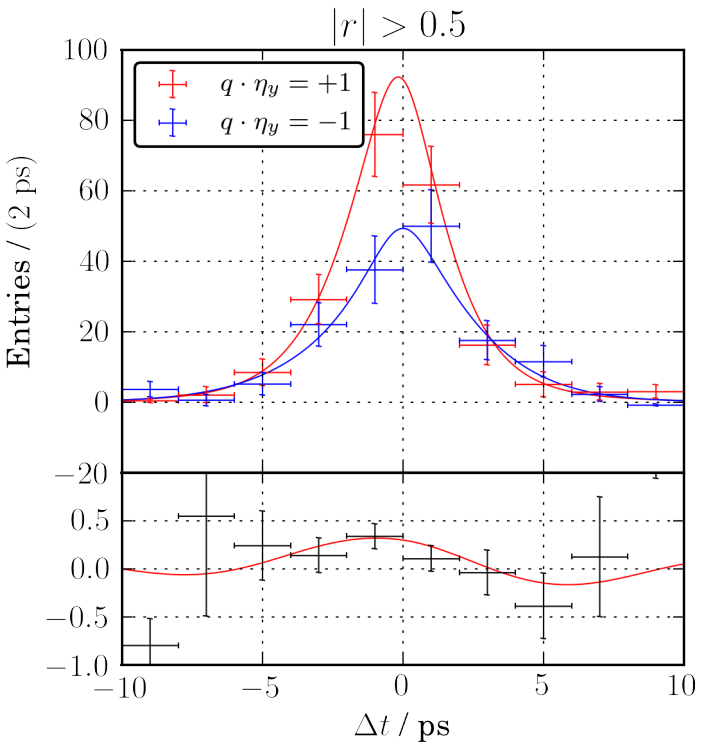
$B(\omega K^0)$	=	$(4.5 \pm 0.4\ (stat) \pm 0.3\ (syst)) \times 10^{-6}$
$B(\omega K^+)$	=	$(6.8 \pm 0.4\ (stat) \pm 0.4\ (syst)) \times 10^{-6}$
$A(\omega K^0_S)$	=	$-0.36 \pm 0.19(stat) \pm 0.05(syst)$
$S(\omega K^0_S)$	=	$+0.91 \pm 0.32(stat) \pm 0.05(syst)$
$A(\omega K^+)$	=	$-0.03 \pm 0.04(stat) \pm 0.01(syst)$

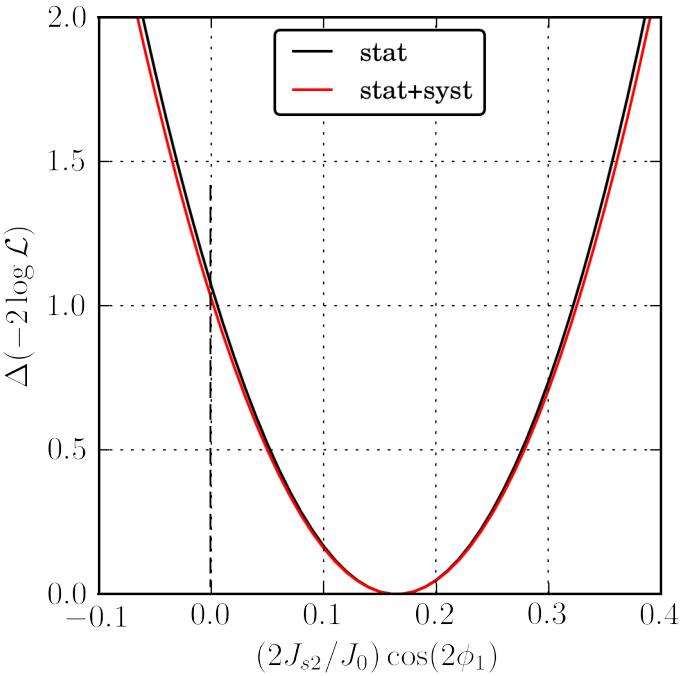
First evidence for CP violation in $B^0 \to \omega K^0_S$

Sin(2ϕ_1)/Cos(2ϕ_1): $B^0 \to D^{*+} D^{*-}$ Ks

M. Ritter



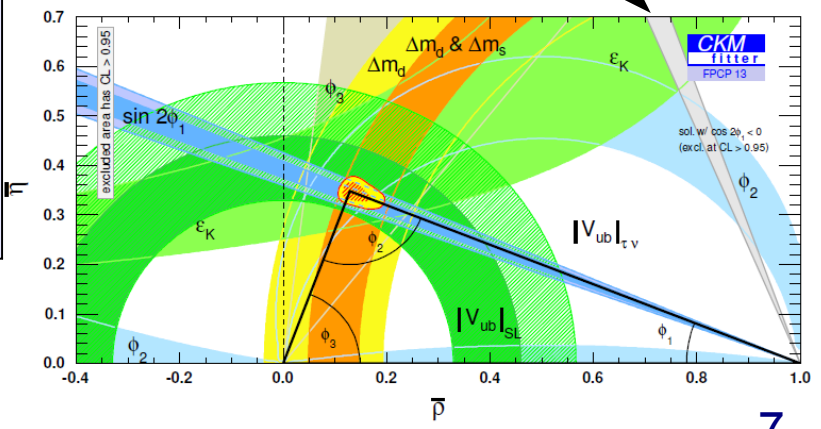




$$A_{CP} = \eta_y J_c/J_0 \cos(\Delta m_d \Delta t) - ((2J_{s1}/J_0)\sin(2\varphi_1) + (2J_{s2}/J_0)\eta_y \cos(2\varphi_1))\sin(\Delta m_d \Delta t)$$

solution excluded @ 84 % CL

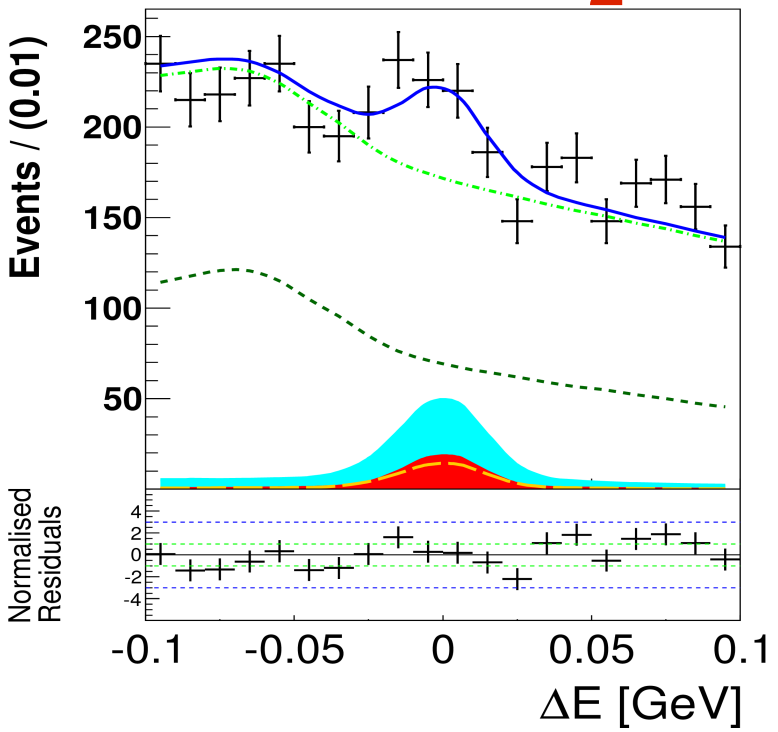
$B(D^*D^*K^0_S)$	$= (5.4 \pm 0.4\ (stat) \pm 0.4(syst)) \times 10^{-3}$
$J_c/J_0(D^*D^*K^0_S)$	$= 0.37 \pm 0.10\ (stat) \pm 0.02\ (syst)$
$(2J_{s1}/J_0)\sin(2\varphi_1)(D^*D^*K^0_S)$	$= 0.30 \pm 0.16\ (stat) \pm 0.03\ (syst)$
$(2J_{s2}/J_0)\cos(2\varphi_1)(D^*D^*K^0_S)$	$= 0.16 \pm 0.16\ (stat) \pm 0.03\ (syst)$

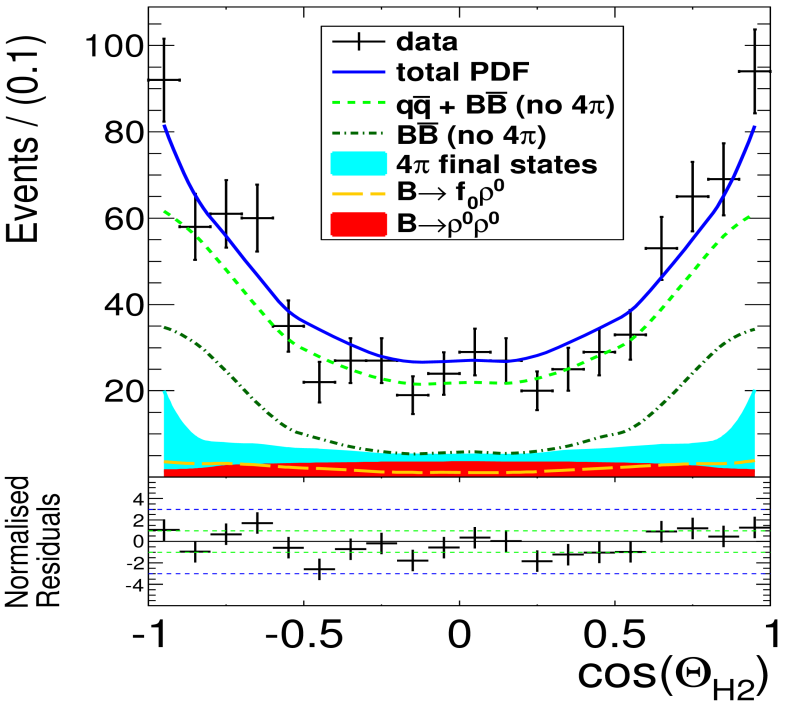


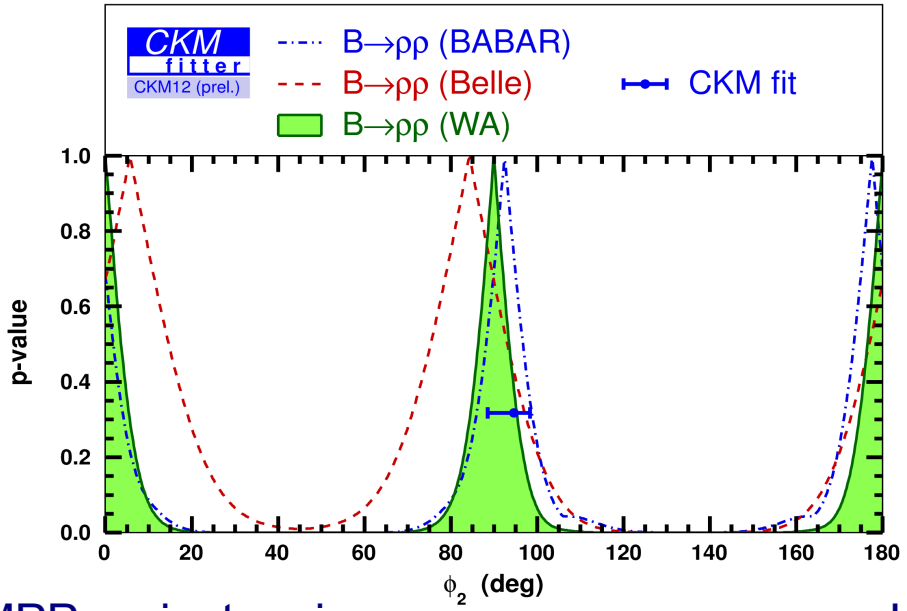
preliminary

ϕ_2: $B^0 \to \rho^0 \rho^0$

PRD 89, 072008 (2014)







Br(B→ $\rho^0\rho^0$)=(1.02 ± 0.30 (stat) ± 0.15(syst)) x 10^{-6}

$f_L = 0.21^{+0.18}_{-0.22}$ (stat) ± 0.15 (syst)

Isospin analysis with Belle results only:

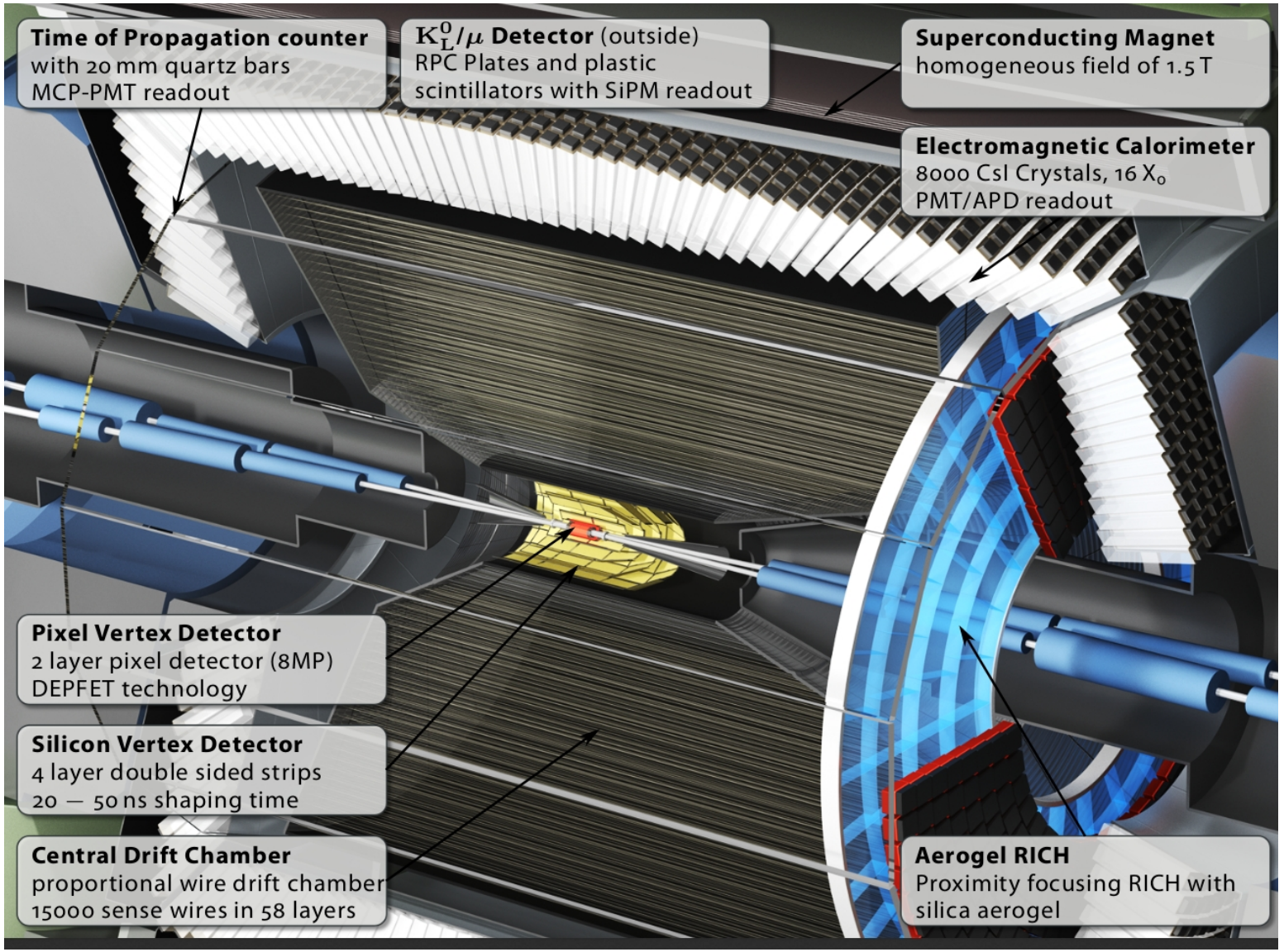
$\phi_2 = (84.9 \pm 12.9)°$

update of B → $\rho^+\rho^-$, $\rho^\pm\rho^0$ needed

Ongoing at MPP

Belle II

- Work on the upgrade/replacement of various sub-detectors has started
- Expected recorded integrated luminosity: 50 ab^{-1}



Belle II Pixel Vertex Detector

- 40 times increase of luminosity → higher background
- Lower boost → smaller separation between the B mesons

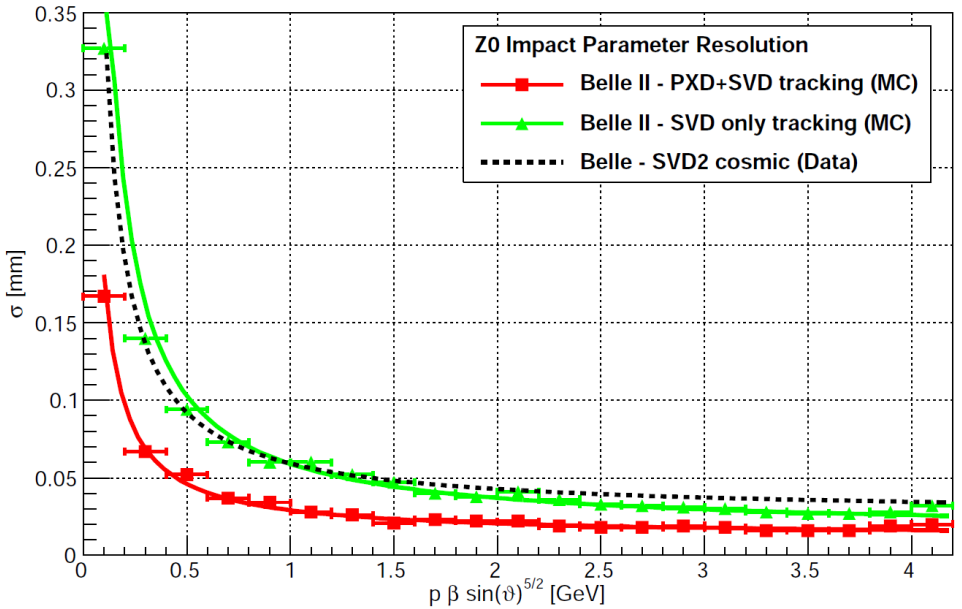
→ Pixel detector needed

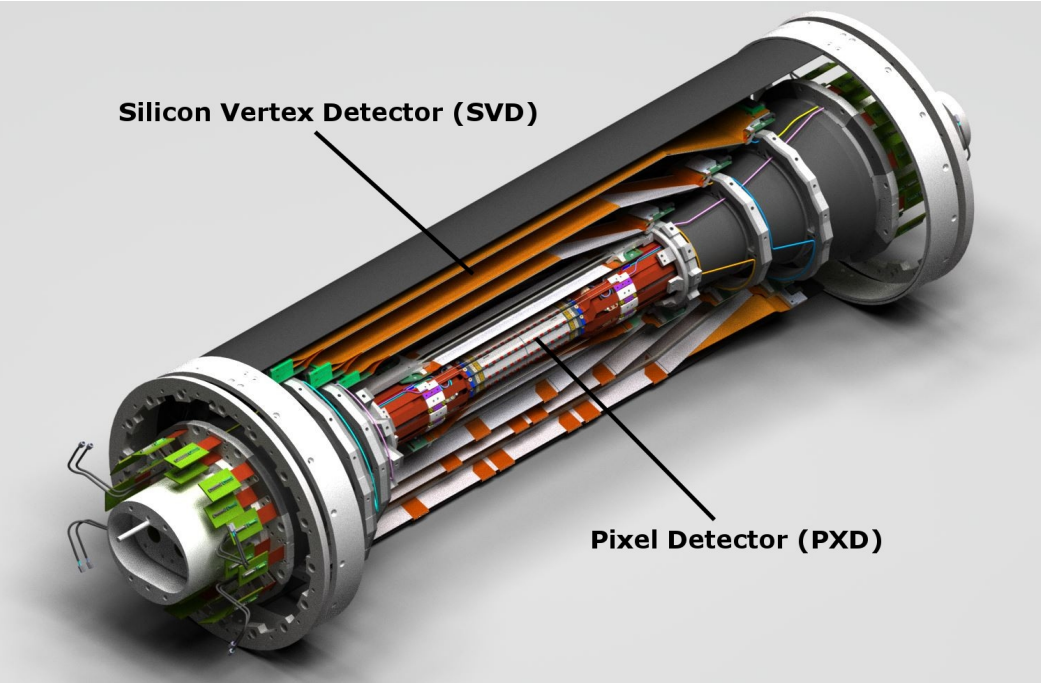
Most suited technology : DEPFET

- Innermost detector system as close as possible to IP
- Highly granular pixel sensors provide most accurate 2D position information

- Reconstruction of primary and secondary vertices of short-lived particles
- Decay of particles is typical in the order of 100μm from the IP

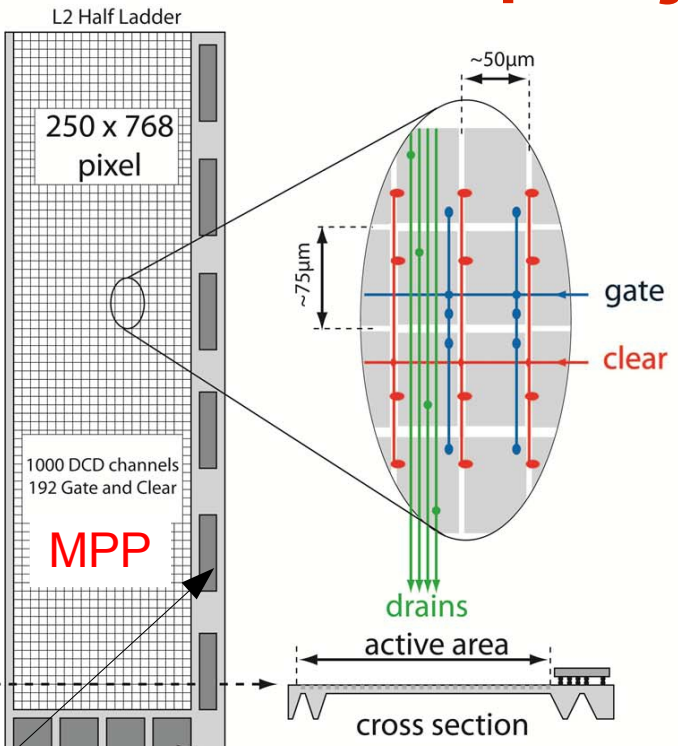
Significant improvement in the IP resolution



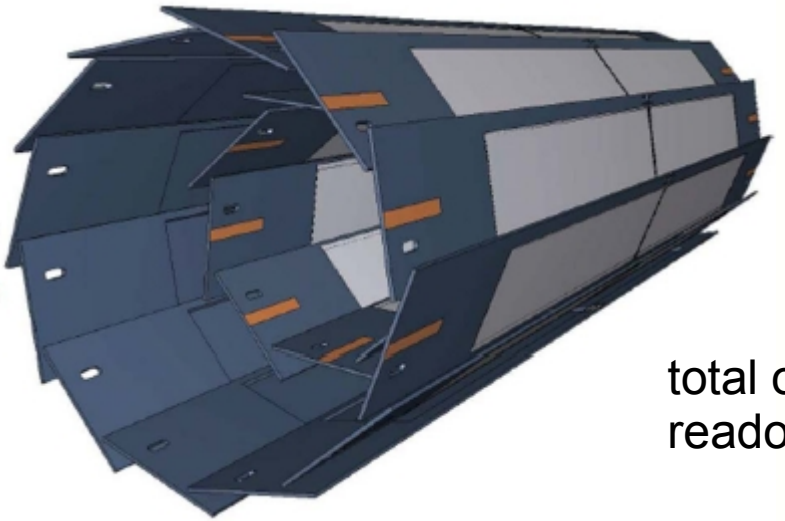


PXD project - layout

Half ladder:
768 rows
250 cols
15 x 70
(85) mm

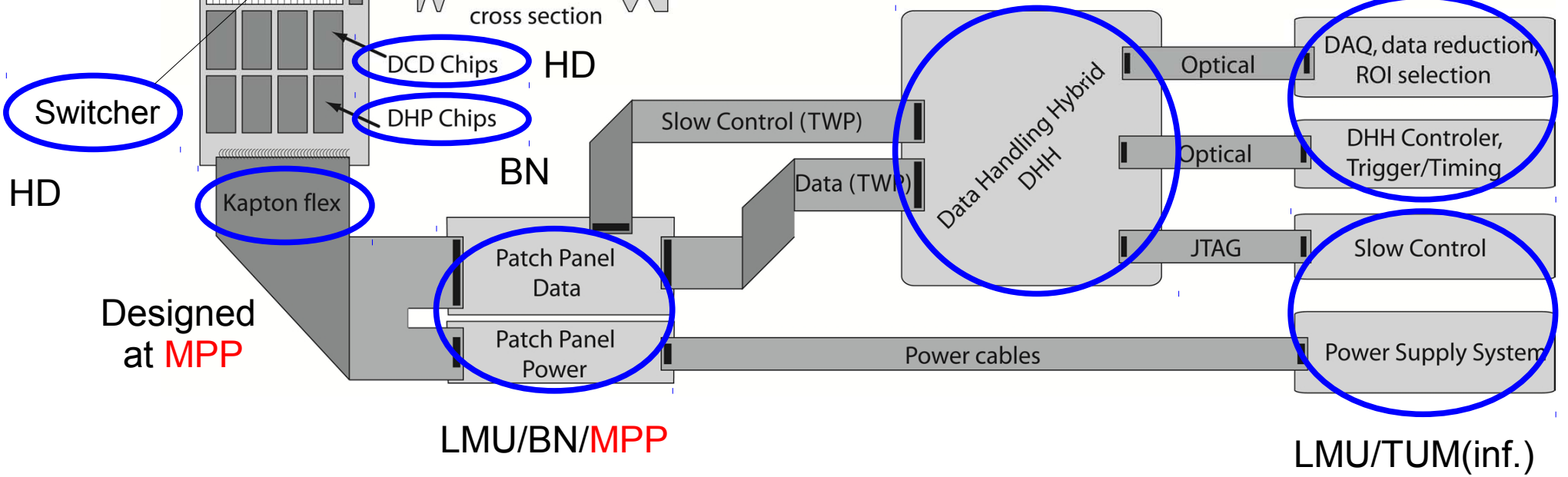


Pixels: 50 x 60(75)µm



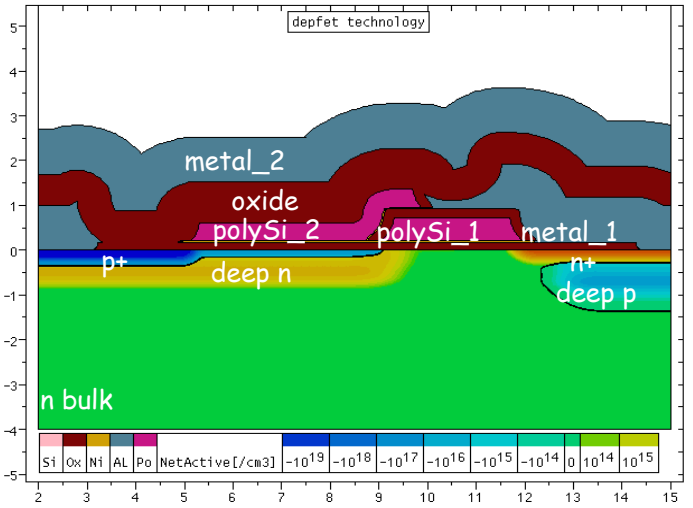
Thickness: 75 µm

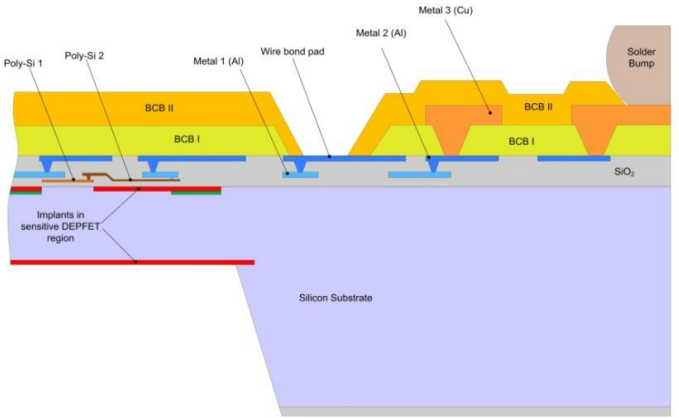
total of 8 Mpx
readout: 20 µs



DEPFET production

- Phase 1:
  - implantations
  - oxide/nitride depositions
  - polysilicon deposition
- Phase 2:
  - metal 1 (alu)
  - insulation oxide/contacts
  - metal 2 (alu)
- Phase 3: outside main clean room
  - thinning
  - BCB insulation
  - copper
  - BCB passivation

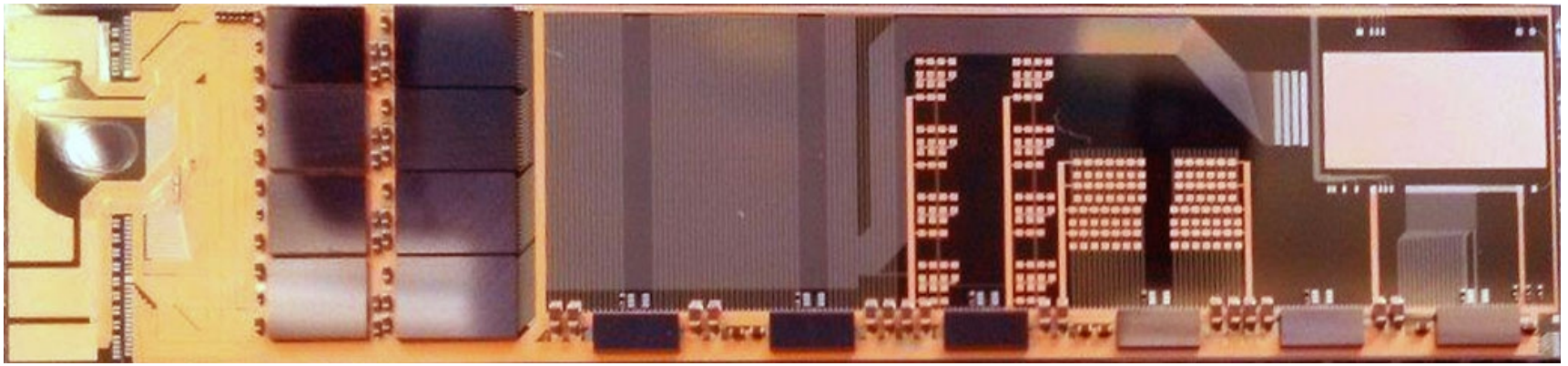




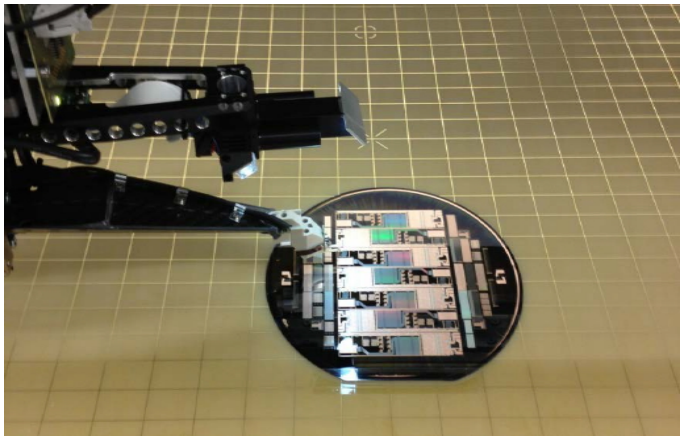
- Phase 1 completed.
- Metal layer processing started in November
  - After EMCM tests were considered sufficient
- New sensor production foreseen after the end of phase 3

Electrical Multi-Chip Module

Design and build a fully functional Belle II half-ladder (module) without DEPFET



- Basically an electrically active prototype of a half-ladder
- It can be equipped with ASICs and operated like a real module (without giving signals)
- Test vehicle for metal system and electrical performance of periphery

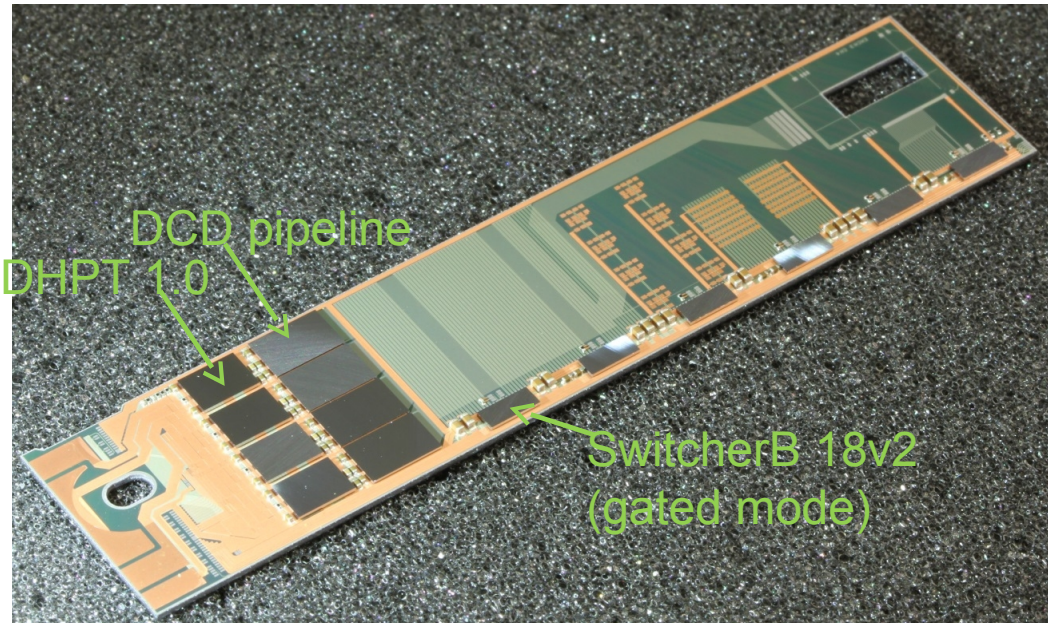


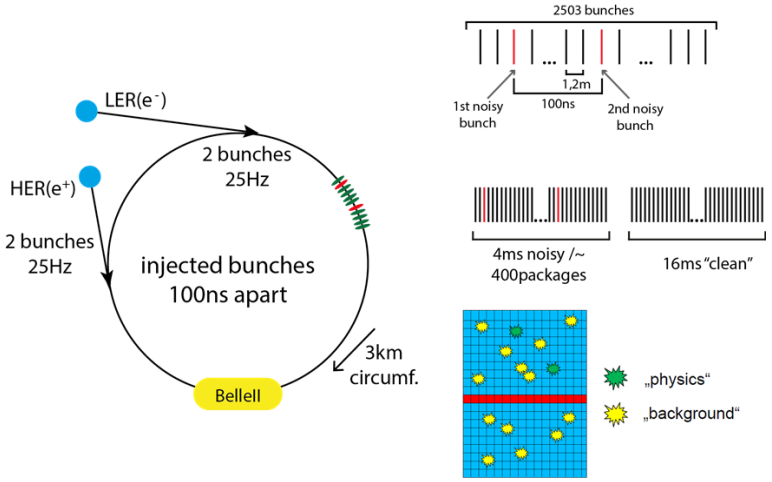
EMCM assembly

- Yield problems during metallization have been resolved
- Design of metal layers is finished
- HLL started a pilot run with three hot wafers, to be finished by March 2015

EMCM test with ASICs

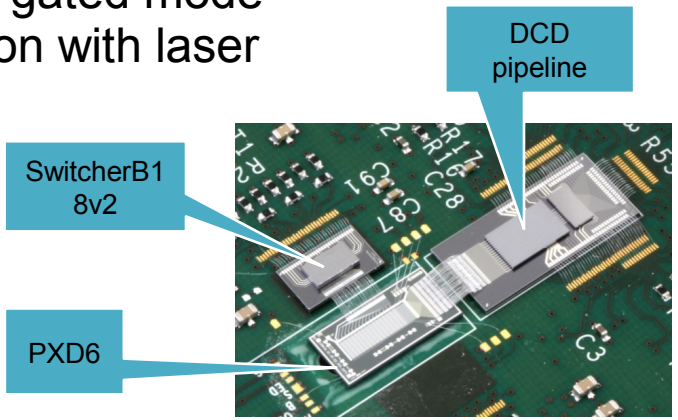
- Two modules: one with a small matrix
- Can configure and run all ASICs simultaneously
- The DATA links can be used at lower bandwidths
  - Full test of EMCM is possible.
- Problem with data link to readout electronics
  - some links crash when triggering readout
  - should be resolved in next iteration of DHPT





- Freshly injected bunches need to cool for > 4 ms (KEK value)
- When "noisy" bunch crosses the interaction region, make DEPFET sensors blind

Testing gated mode operation with laser



ASICs work, trigger sync between laser and readout ongoing

Mechanics

Installation (collaboration with DESY)

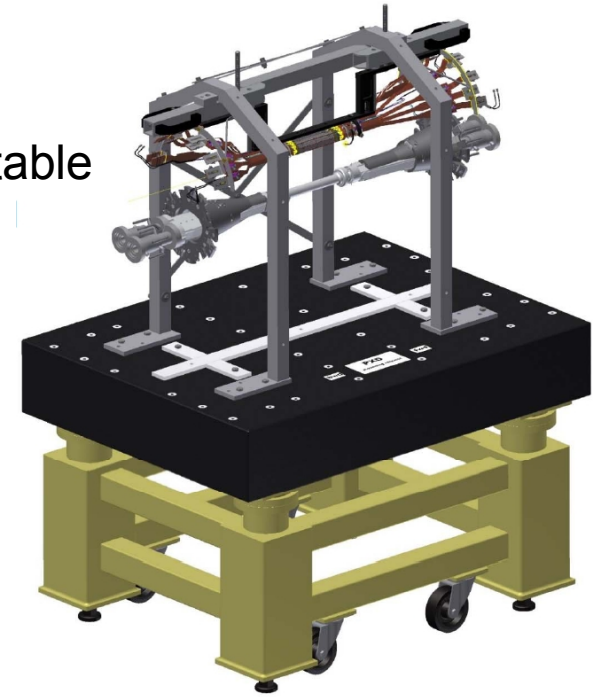
- Decision at KEK to use MPP proposal
- Decoupling from machine

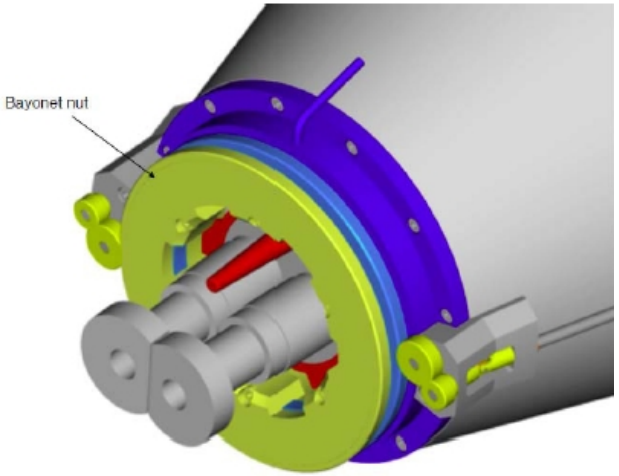
Installation mockup: MPP

PXD will be assembled at MPI

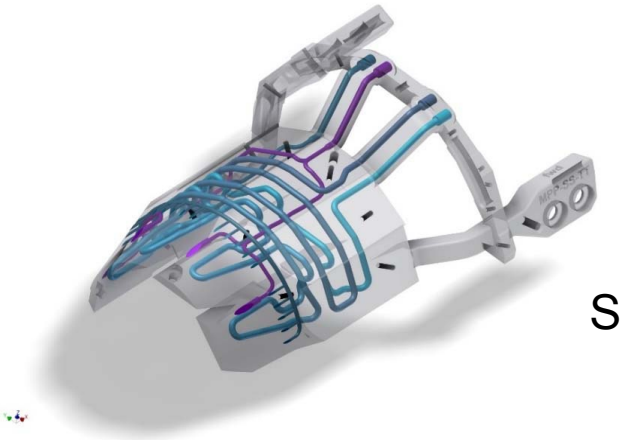
- kapton soldering and bonding
- Module assembly (with HLL)
- 2 half shells will go to KEK

Assembly table





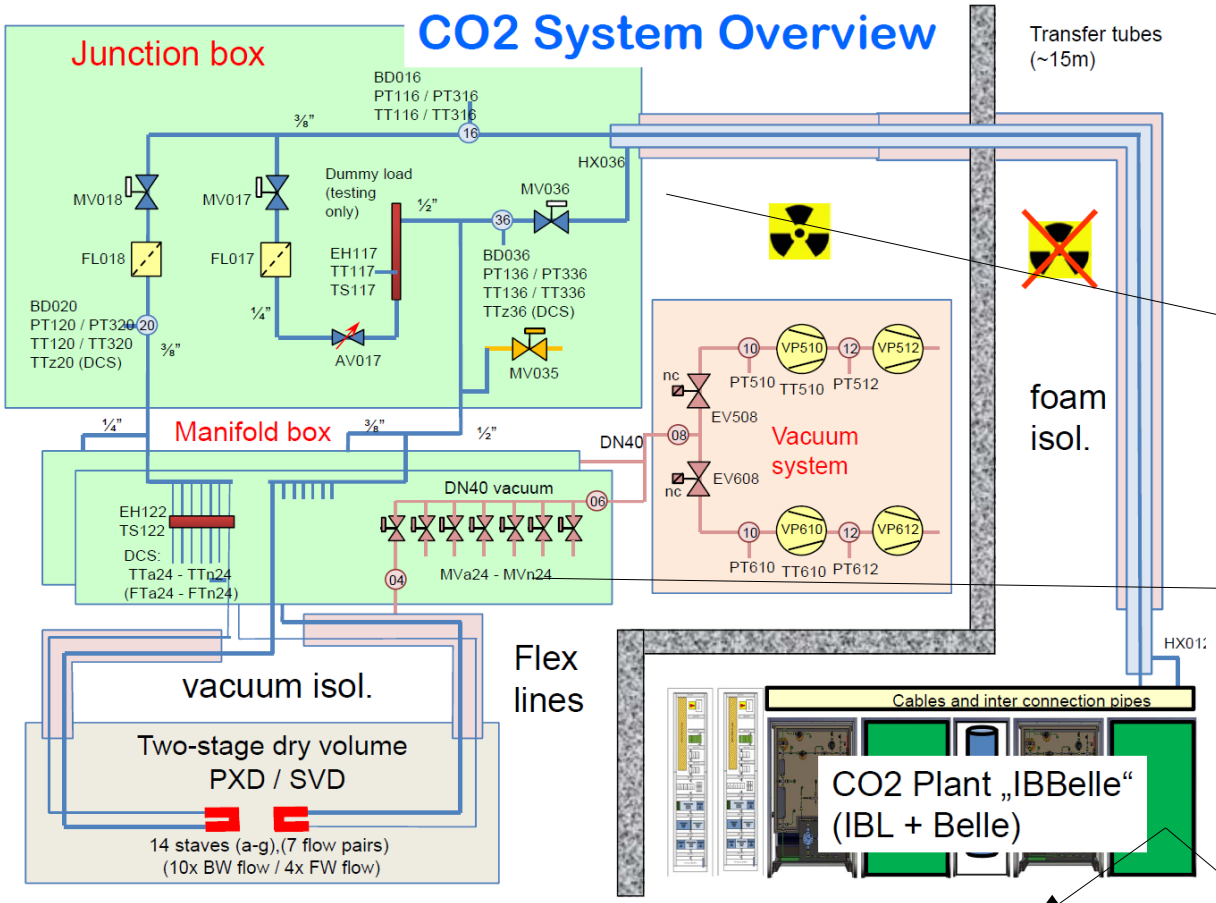
Remote Vacuum Connection: DESY

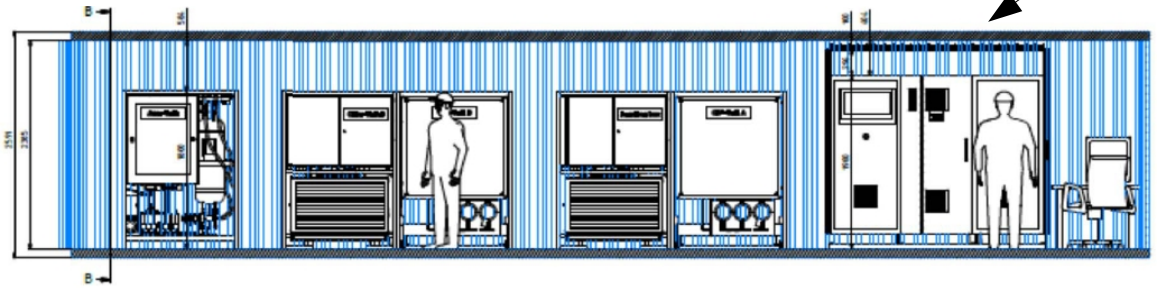


Support - cooling block

Cooling

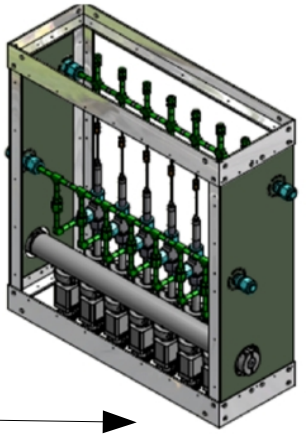
CO2 System Overview





40’ Container, to be placed outside of Tsukuba hall

Common development ATLAS/BelleII

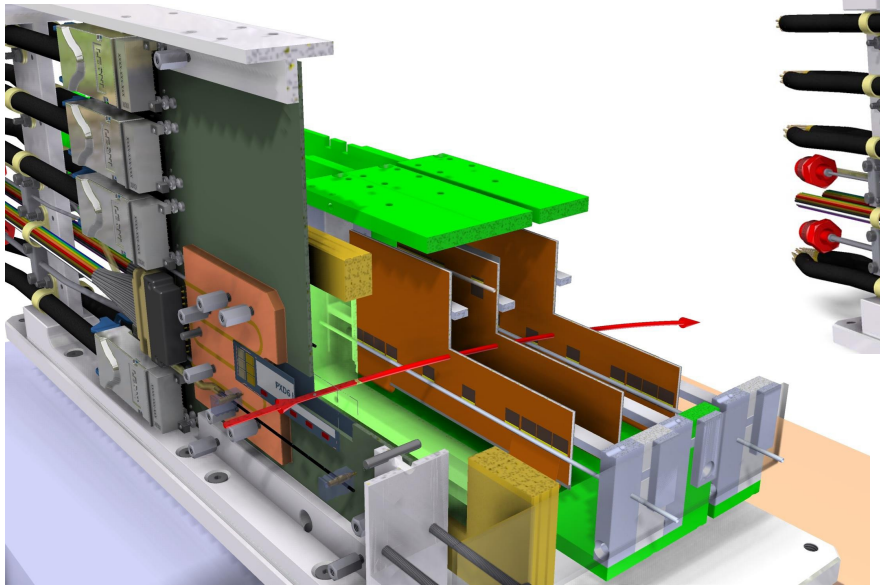


- ATLAS version
- BelleII version construction in 2015 at MPP

Test beam

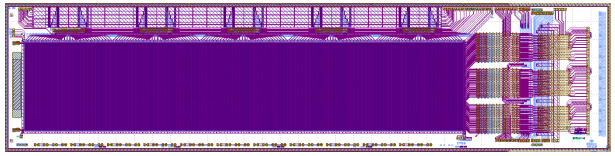
- Belle II vertex detector (PXD + SVD) telescope test beam in DESY in January 2014
- All systems ran smoothly

Important contribution of the MPP group

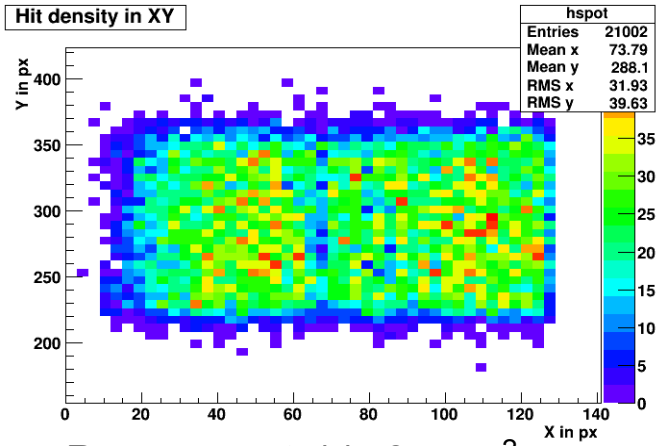


Mechanics

Cooling



PXD sensor production



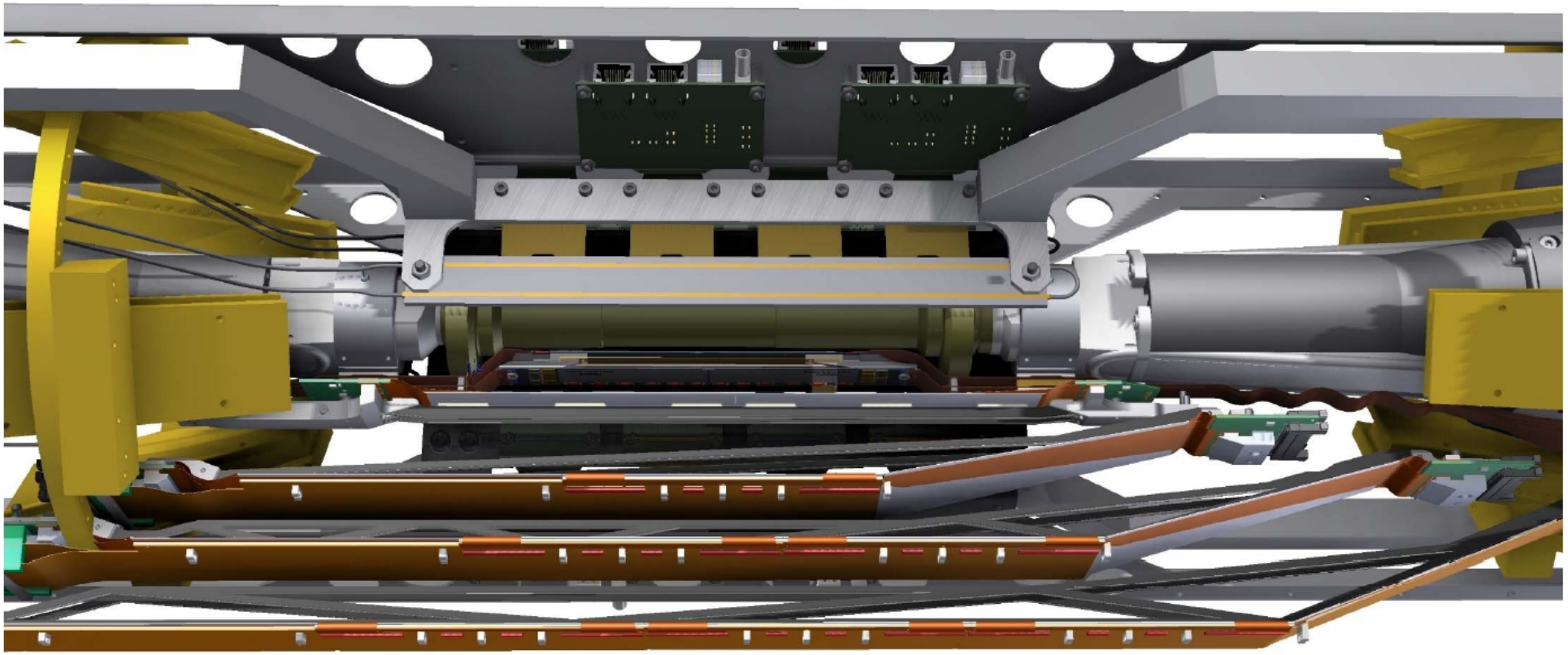
Beam spot 11x6 mm^2

- Next beam test in DESY foreseen for the end of 2015 / early 2016
- 2 sensors (ladders) together with final SVD ladders

BEAST Phase II

Background detector for the commissioning of the Belle II experiment

- Entire VXD sector: 2 PXD layers + 4 SVD layers
- Scintillator tiles with SiPM readout based on CALICE / T3B system for background monitoring (MPP/ILC)
- ATLAS IBL test sensors (Bonn)
- BGO crystals (NTU) , crystal diamonds sensors (Trieste)



Physics preparation

- The Belle II Physics preparation follows two paths
- MPP Belle II team participates to both activities

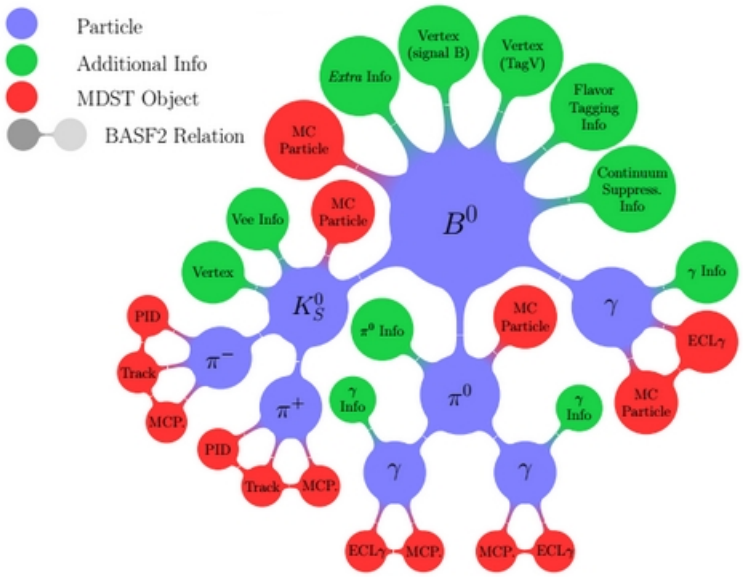
The "Belle II - Theory Interface Platform" is a joint theory-experiment program to study the potential impacts of Belle II

New aspects of Belle II?
- Improvements from new hardware
- New analysis techniques

Recent developments and new avenues in theory?
- Progress in QCD
- New physics models and current constraints
- New observables

New ideas & results

Physics software development

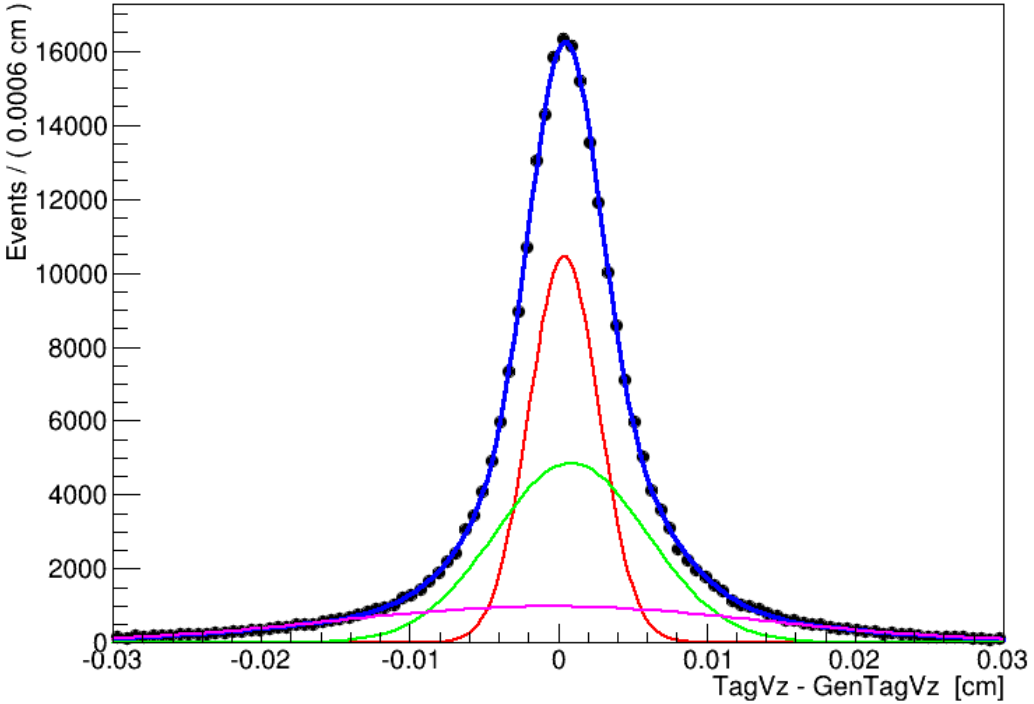


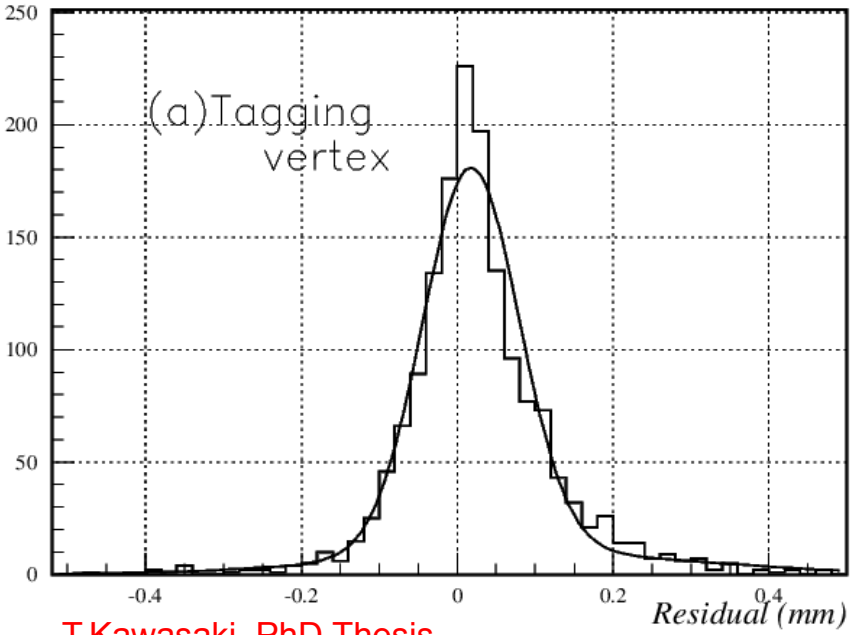
Particle
↪ minimal representation of the *"physical"* particle

XYZAnalysisDataObject
↪ information relevant for certain type of particles
↪ information relevant for certain type of tasks/analysis

Tag side vertex resolution

Important improvement in the tag side vertex resolution

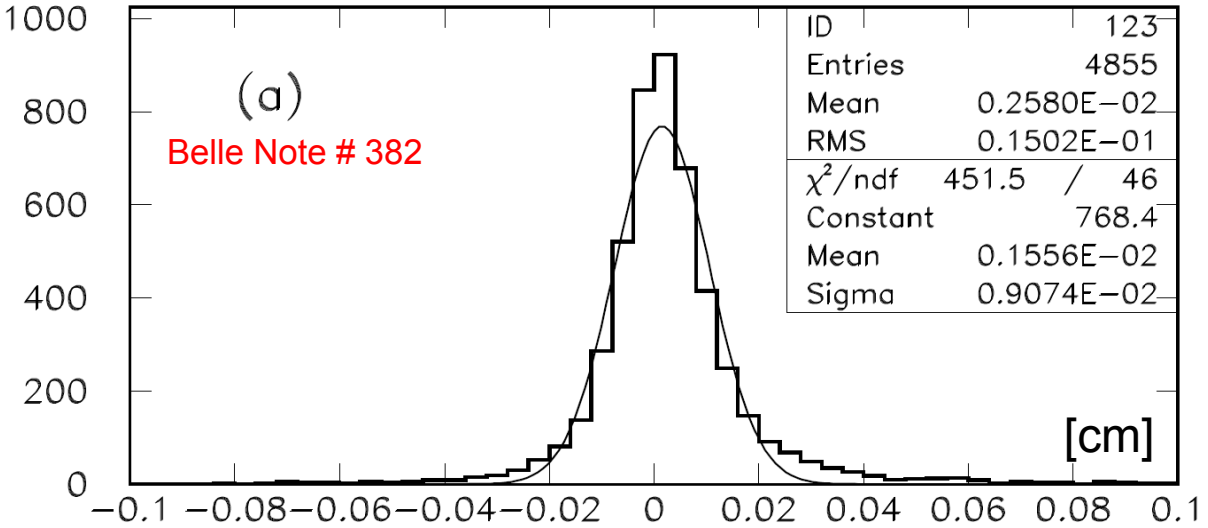




T.Kawasaki, PhD Thesis

Belle II
- Shift = 3.9 μm
- Resolution = 60 μm

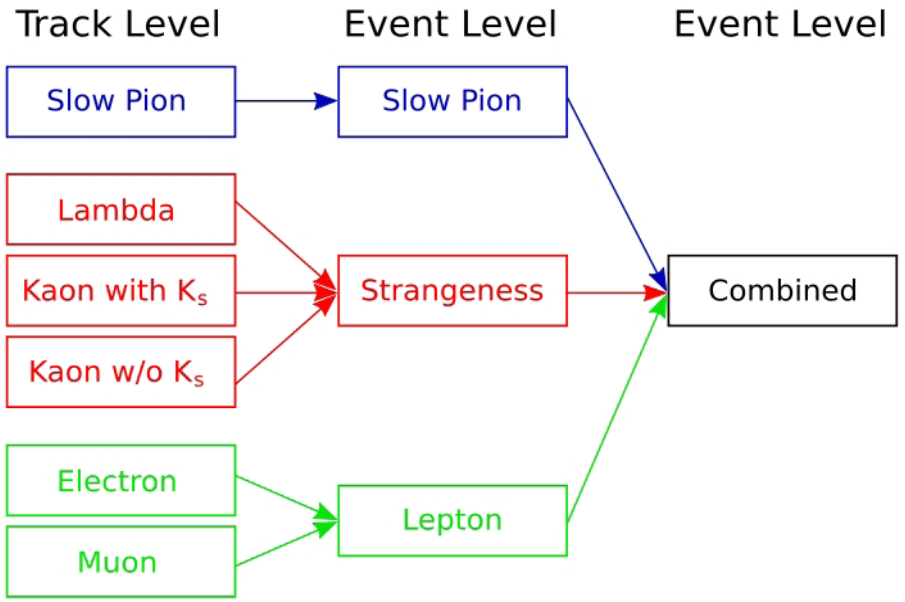
Belle
- Shift = 29 μm
- Resolution = 89 μm

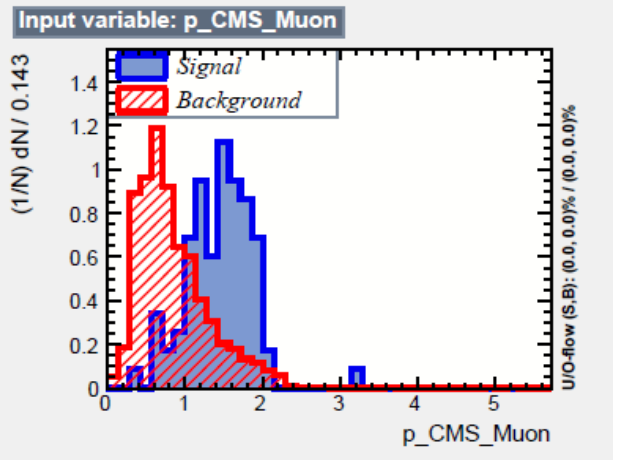


F. Aubudinen + KIT

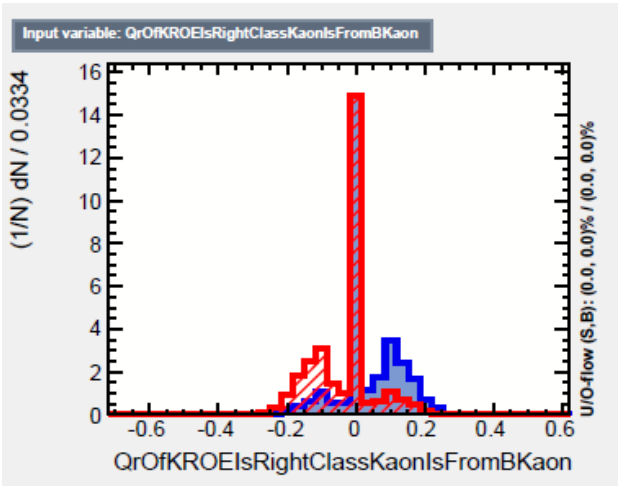
Flavor tagging

Multivariate analysis in three steps

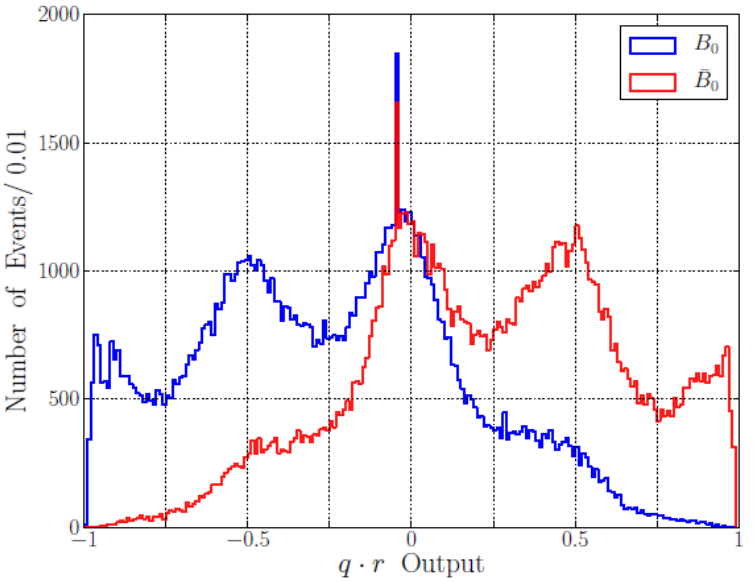




Event level input example

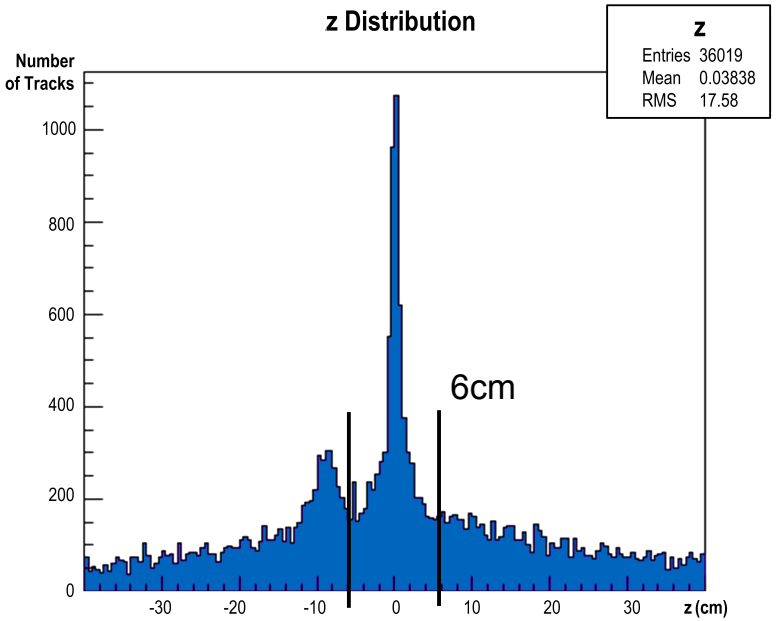


Combiner input example

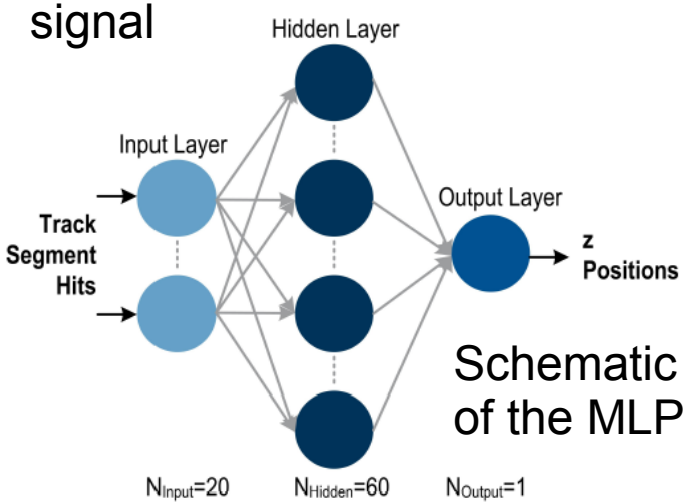


Output example

Z vertex trigger with Neural Network

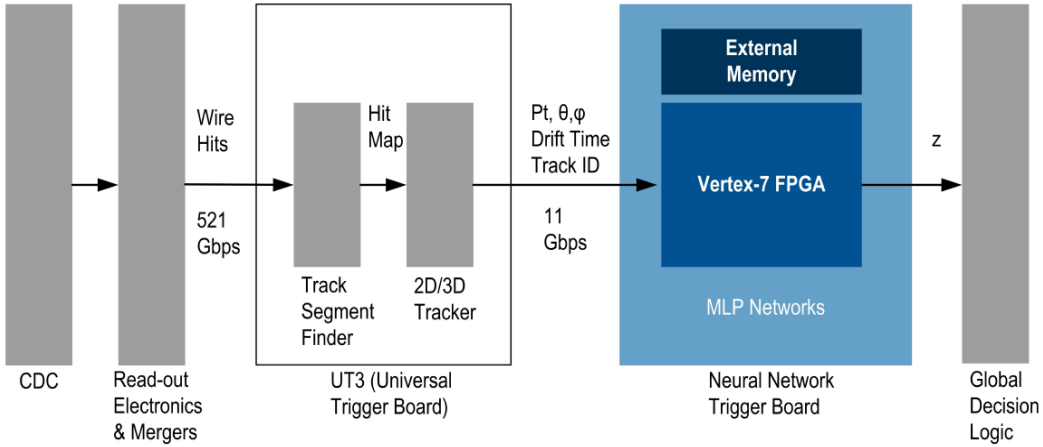


- Distribution of the z-vertex position in Belle
- Only the narrow peak around z = 0 cm corresponds to the interesting physics signal

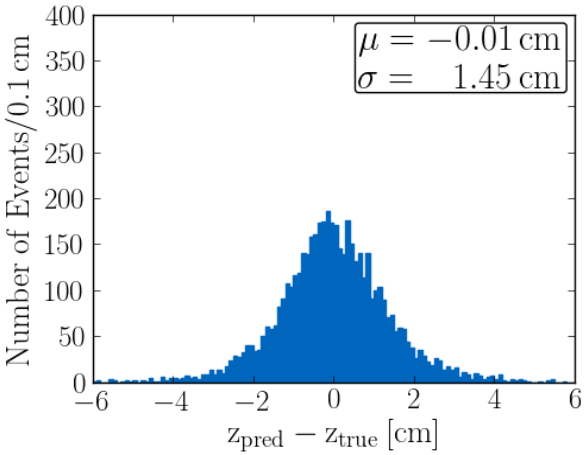


Schematic drawing of the MLP structure

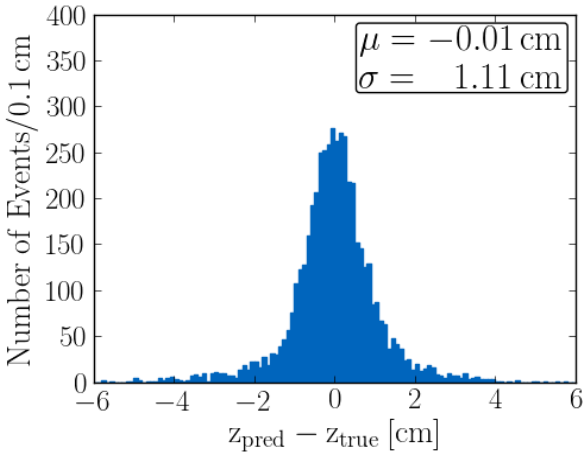
TUM: S. Neuhauser, S. Skambraks + Vienna + KIT
BMBF funding requested



System diagram of the CDC Trigger and Neural Network z-Trigger subsystem



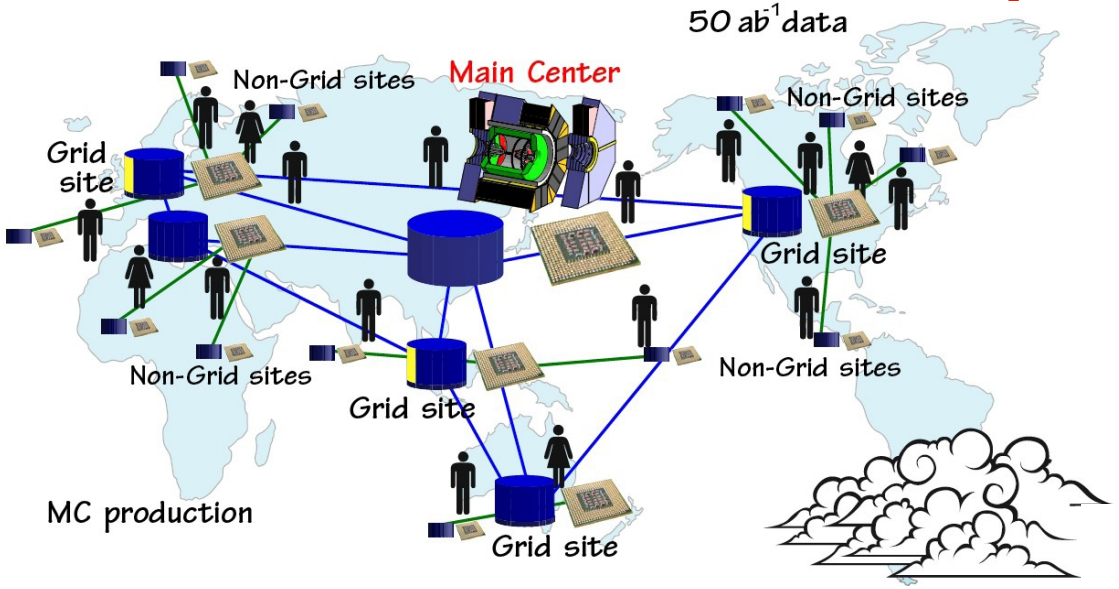
p_T = [0:25; 0:26] GeV



p_T = [5; 7] GeV

Results

Computing

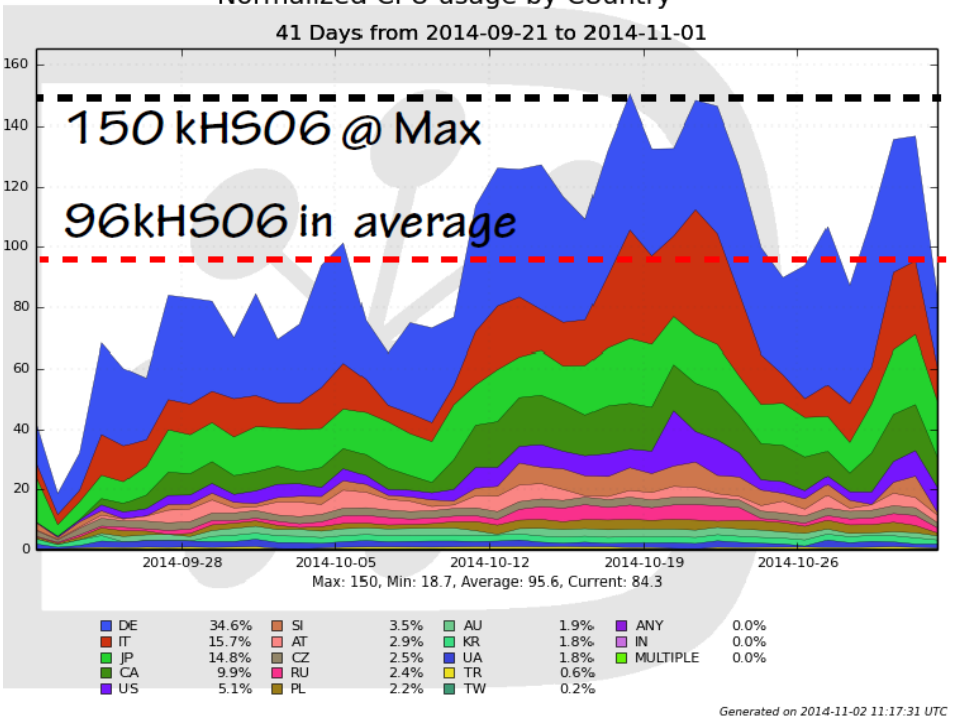


- Belle II adopts GRID computing
- Only Monte Carlo production so far
- Large Germany contribution during last MC production

On average during last MC production

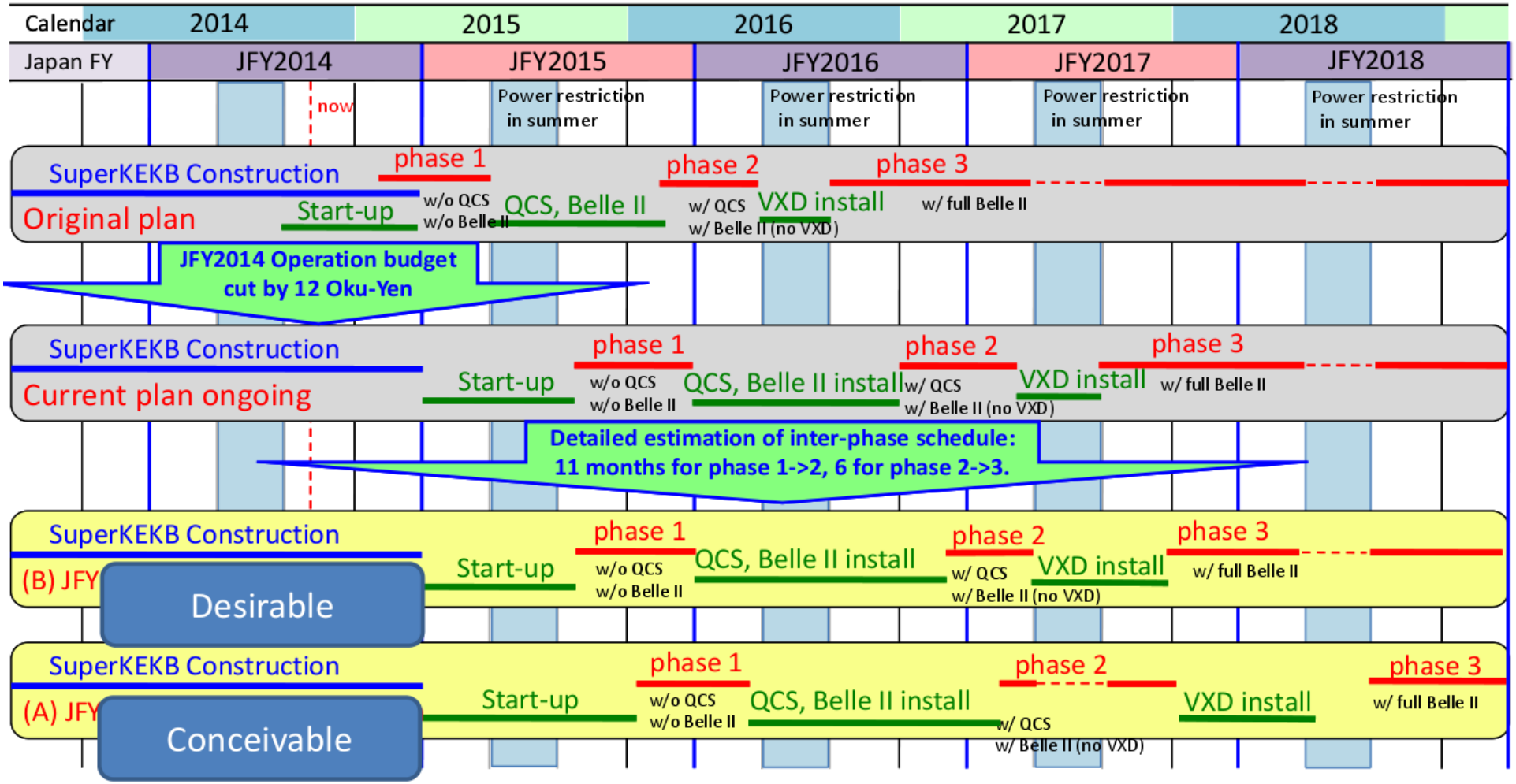
Country	kHS06
Germany	58.760
DESY	45.606
KIT	6.919
MPPMU	6.235

Normalized CPU usage by countries



Belle II general schedule

- Two different schedules depending from KEK budget
- Budget will be clearer in the very end of December



- IBBelle Construction: 2015, to be delivered to KEK early 2016
- Module Production will start end of 2015 and finish in 2016
- Shipment of the PXD to KEK and integration: beginning of 2017 (earliest)

Summary

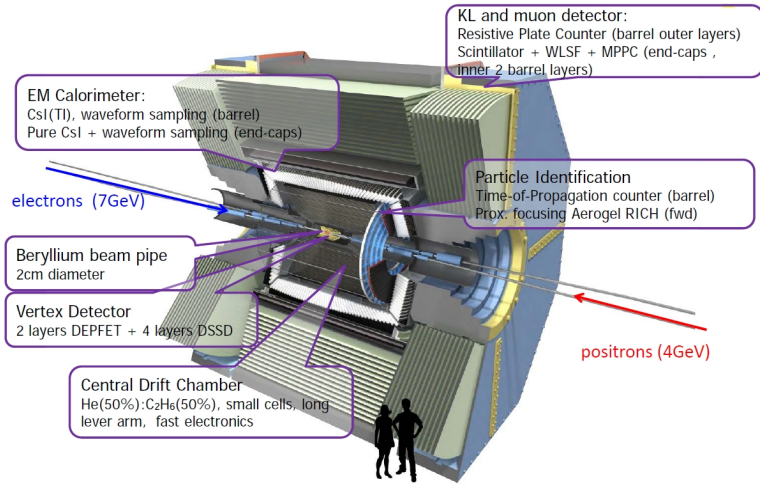
Many activities of the MPP group inside the Belle/Belle II collaborations

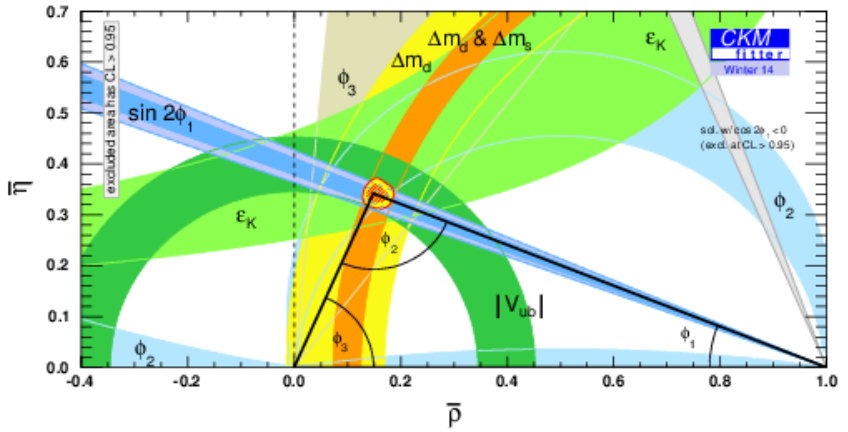
Pixel Vertex Detector (PXD)

- Sensors production
- Electronic tests
- Cooling system
- Mechanics
  - Installation method
  - Modules and detector assembly
  - Support – cooling blocks

Test beams:

- 2014 DESY telescope test
- End 2015 / early 2016 DESY test
- Beast Phase II





Belle data analysis with the full dataset:

- ϕ_1, ϕ_2 measurement

Belle 2 preparation for physics

- Belle II Theory Interface Platform
- Belle II physics software development
  - Vertexing
  - Flavor tagging

Z vertex trigger with neutral network

Computing:

- RZG as Belle II Tier 2